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HOW TO DESIGN A MODEL FOR PROTOTYPING CROPPING SYSTEMS? EXAMPLE OF SIMBA FOR BANANA-BASED SYSTEMS

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Introduction

Using models to design cropping systems is of growing interest but it cannot rely only on existing crop models (Keating et al., 2003; Stöckle et al., 2003) because they do not necessarily cover the major limiting factors and the major externalities in a given context. It may be better to develop an *ad hoc* model, which captures the specificities of the cropping system, using generic knowledge, local data, and expert knowledge. The model should also produce the indicators, which are relevant to assess the sustainability of the system. The example of the SIMBA model, especially dedicated to banana-based cropping systems simulation and prototyping in French West Indies, illustrates our approach. Here, we present the methodology used to build the model and the indicators used to assess the simulated systems. We discuss the choices of modeling precision, we particularly focus on the trade-offs between high precision formalisms demanding in parameters and calibration, and simple formalisms that rise to easier calibration and use but with less accuracy or smaller ranges of validity.

Model description

The SIMBA model, was developed in the Stella platform, it includes modules that account for the major processes. It simulates, at the week time-step, the effects of crop rotations and agromanagement on soil, water, nematode, yield, and economic outputs with a sound balance between representation of the major phenomena and keeping the model simple to reduce the parameterization costs. Instead of starting from an existing crop model, adapting it to the banana-nematodes system, and deriving some indicators from the output variables, we created a new model to produce the assessment indicators based on existing knowledge. The evaluation criteria of the simulated systems were profit margin and environmental risks. Consequently, the yield and the state variables of the system, and their dynamics, were taken into account in order to generate these outputs. Two types of formalism were developed to compute these variables. For processes that can be simulated biophysically, process-based modules were developed. These included plant growth, plant population structure, soil cover, physical soil properties, water balance, and plant-parasitic nematode population densities. For processes that cannot be simulated biophysically, semi-qualitative indicators based on expert systems and fuzzy logic were developed, using some of the outputs of the biophysical modules. The biophysical system is driven by a technical system (as defined by Lançon et al., 2007) that can be generated by decision rules or forced by the user. Contrary to the structure of traditional cropping system models, the core of SIMBA is the plant population module SIMBA-POP (Tixier et al. 2004). It allows simulating the evolution of the banana population over years. Indeed, the initially homogeneous plant population becomes heterogeneous after few cropping cycles, i.e. plants in the field can be at different phenological stages at the same time. This process has a central influence on crop yield and on water and nitrogen balances, soil cover, pest dynamics, and labour uses. Linked to the module, the growth module SIMBA-GROW is calculated separately for each cohort defined in SIMBA-POP. This module includes simulation of leaf area index (LAI), vegetative biomass (leaves, pseudo-stem, roots), and yield (number and weight of fruits per bunch). The nematode population dynamics are simulated with the SIMBA-NEM module (Tixier et al., 2006); it was calibrated for *Radopholus similis* and *Pratylenchus coffeae*, which are the plant-parasitic nematodes that generate the most extensive root lesions and that are considered among the most detrimental pathogens of banana. This module is based on a cohort chain structure and a logistic function to describe population growth in relation with i) an environmental carrying capacity depending on the available banana root biomass, ii) an intrinsic growth rate, and iii) the interspecific competition. Soil water content and nematicide applications are considered the main variables influencing the intrinsic population growth rate of each species. This module illustrates how we integrated all the knowledge available to account for one major biological process that usual models cannot simulate. Expert knowledge was also used in the linkage of different module. For instance, the calculation of stresses for growth includes fuzzy logic rules to account for the effect of nematodes populations, drought, or soil compaction. Another specificity of the SIMBA framework is the necessity to assess the simulated system on the basis on their environmental risks. Thus, we developed a pollution risk indicator called Rpest (Tixier et al., 2007) using existing methods of evaluation (Girardin et al., 2000) that we adapted to the tropical context and to their application within a modeling framework. Rpest provides dynamic assessments through a linkage with the biophysical modules of SIMBA that simulate state variables of the system. We conducted an expert validation; it demonstrated that Rpest ranks cropping systems by risk as well as experts do. Using the same method, we built indicators to assess the soil fertility and the erosion risk (Rfert and Rero). To be able to simulate a generic cropping systems the model is driven by farmer's decision rules. These rules allow accounting for the decision process of the farmer in reaction to the system evolution and not only a scheduled calendar of task as most models do. The global structure of the SIMBA model (Figure 1) shows this comprehensive and specific approach of the cropping system simulation. These decision rules interact with the state variables of the systems. Finally, a multicriteria evaluation permits through a weighting procedure to rank all the simulated systems.

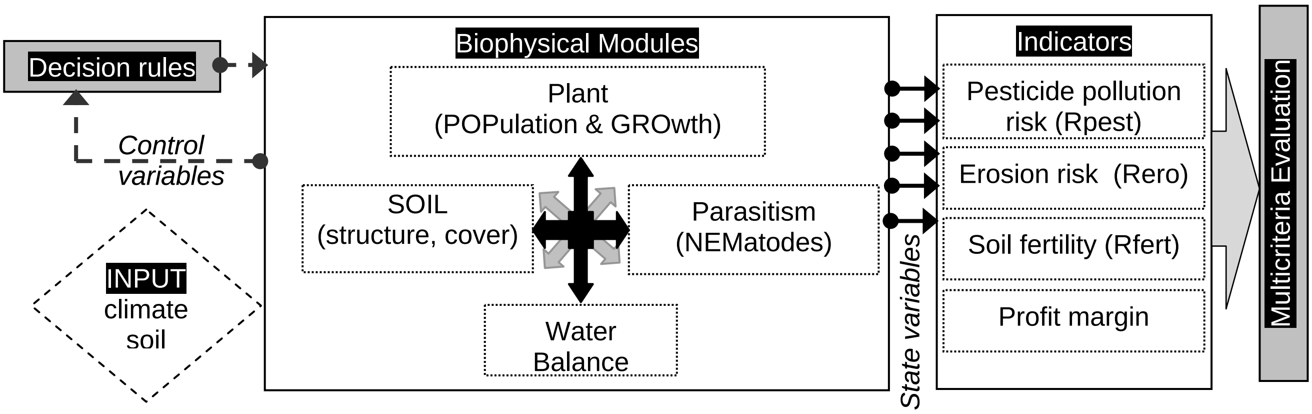

Figure 1. Simplified structure of the SIMBA framework

Conclusions

This example provides evidence that an early integration of expected outputs needed for prototyping within the model allows a more efficient design and assessment of cropping systems. This methodology of prototyping sustainable cropping systems is generic and aims to be applied to other complex agro-ecosystems in other contexts, where sufficient knowledge and local data are available.

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